NEW MEXICO STATE UNIVERSITY

OBSERVATORY

BOX Y
UNIVERSITY PARK
NEW MEXICO USA 88070

TELEPHONE:
LAS CRUCES, N. M.
505-646-2611

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JUPITER'S RED SPOT IN 1965-66

H. Gordon Solberg, Jr.

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H. Gordon Solberg, Jr.

New Mexico State University Observatory

Las Cruces, New Mexico

ABSTRACT

The latitude and longitude of Jupiter's Red Spot were measured from photographic plates obtained between 1 July 1965 and 4 June 1966 at the New Mexico State University Observatory. The Red Spot increased irregularly in System II longitude from 24° in July 1965 to 28° in June 1966. The zenographic latitude of the Red Spot remained near its mean value of -22°.3.

Numerous fluctuations in the position and dimensions of the Red Spot were noted, and evidence for a relationship between the Red Spot and rapidly moving features on the STB is cited. An oscillation in the longitude of the Red Spot with a period of 88 ± 10 days may have been produced by rapidly moving dark spots on the north edge of the STB, which moved 360° in longitude with respect to the Red Spot in 91 days.

INTRODUCTION

In an earlier paper (Reese and Solberg, 1966), hereafter referred to as (I), it was reported that Jupiter's Red Spot undergoes rapid, short-term changes in longitude, as well as slow oscillations in latitude. This measuring program has been continued at the New Mexico State University Observatory. A large number of photographic plates obtained during the apparition of 1965-66 between 1 July 1965 and 4 June 1966, as well as a more precise method for determining Jovian longitudes, have made possible the detection of several types of short-term changes in the Red Spot which were not previously known to exist.

METHOD

The procedure used for measuring the Jovian longitude of the Red Spot was basically the same as that reported in (I). A more rigorous formula for determining longitude was used during the 1965-66 apparition, in order to reduce an error inherent in the previously used formula when the Red Spot was far from the central meridian. To further increase the accuracy of the measurements, six images per plate rather than four were measured.

The latitude was measured in the same way as described in (I), except that four images, rather than three, were measured per plate.

Increased use of computers made possible improved means of analyzing the data. Smoothed curves were constructed for the positions and dimensions of the Red Spot; these made it possible to detect small changes which are obscured by the scatter among the individual observations and which would not have been apparent if monthly mean values had been plotted, as was the case in (I). In determining the

smoothed position of the Red Spot for a particular date, the measurement obtained on this date was averaged with the measurements of the preceding and following four plates, all observations being given equal weight. Only the longitude exhibited very short-term changes which were masked by the smoothing process; therefore a graph of all longitude data points as well as the smoothed longitude graph will be presented in this paper.

MEASURING UNCERTAINTIES

Since a greater number of images was measured per plate, the probable error of an average quality set of Red Spot measurements was reduced to $\pm 0^{\circ}.12$. The better plates could be measured with a probable error of about $\pm 0^{\circ}.06$. As seen in Figure 1, the scatter of the measurements is about five times the probable error. The significance of this scatter is not known at present; it may be due in part to systematic errors in measuring, or it may be related to very short-term changes in the apparent position of the Red Spot.

Since only one individual (the writer) measured the plates, no corrections were applied to the Spot's dimensions, as was done in (I).

The phase exaggeration, discussed at length in (I), was accurately determined by a long series of measurements of the position of Satellite I as it passed near Jupiter's central meridian at different times during the apparition. The phase exaggeration, amounting to $0^{\circ}.9$ at quadrature, is in reasonably good agreement with the value of $0^{\circ}.6$ reported in (I). This phase effect, incidentially, is not absolute; it varies slightly among different observers.

POSITION OF THE RED SPOT

During 1965-66, the Red Spot increased irregularly in System II longitude, as illustrated in Figures 1 and 2. The mean rotation period during the apparition was $9^h55^m41^s.1$, almost identical to the mean rotation period during the apparition of 1964-65. The drift in longitude was divided into a number of essentially linear segments, from which rotation periods were calculated by the method of least squares (Table I).

With the exception of a sharp rise in latitude near the beginning of 1966, the Red Spot exhibited the slow oscillations which had characterized its drift in latitude during the preceding three apparitions. The mean latitude during 1965-66 was $-22^\circ.3$.

LONG-TERM CHANGES IN LONGITUDE

An overall view of the motion of the Red Spot since 1831 is shown in The Planet Jupiter (Peek, 1958, p. 149). This graph indicates that the Red Spot has deviated more than $\pm 500^\circ$ from its mean position, thereby precluding its connection with an object on the solid surface of Jupiter with a constant rotation period. This does not, however, preclude a relationship between the Red Spot and the solid surface of Jupiter if the solid surface does not rotate at a constant rate. This very large oscillation has not been observed for a sufficiently long period of time to determine if it is periodic. The rotation period, however, has varied periodically since 1831, with a period of about 50 years.

Since 1937 the Red Spot has moved in the direction of increasing longitude at a fairly constant rate. Superimposed on this nearly uniform

increase in longitude is an oscillatory component with a period of approximately eight years and an amplitude of about 10°.

A third type of long-term behavior, with a lifetime of the order of two years, has been detected from measurements of photographs since 1961. Between June 1961 and October 1962, the Red Spot advanced in System II longitude from 0° to 16°. For the next year, between October 1962 and December 1963, the Red Spot remained nearly stationary at 17°. Between December 1963 and June 1966, the Red Spot again increased in longitude, but more slowly, from 16° to 28°.

SHORT-TERM CHANGES IN LONGITUDE

During the past four apparitions, and especially during 1965-66, the Red Spot exhibited a sinusiodal oscillation in longitude with a period of about 88 days and an amplitude of approximately 1°. This oscillation will be discussed in a later section of this paper.

There were at least four short-term changes of less than 2° with lifetimes of one week or less during the 1965-66 apparition: 1) A rapid increase in longitude from 24°.3 to 25°.8 was observed between 12 October and 19 October 1965. There was no marked change in the appearance of the Red Spot, nor was there any unusual activity in the vicinity of the Spot. 2) Between 3 January and 9 January 1966, the longitude of the Spot increased from 25°.9 to 27°.8. At this time the long-enduring STeZ white oval FA was approaching conjunction with the Red Spot. The white oval probably did not produce this increase in longitude, since accurate measurements of photographs during the past four apparitions have indicated that the three STeZ ovals do not influence the Red Spot. During the same period, a dark spot on the north edge of the

STB was nearing the following end of the Red Spot. This dark spot, which apparently affected the Red Spot's behavior, will be discussed in a following section of this paper. 3) A period of rapid, short-term changes in Red Spot longitude occurred between 20 February and 20 March 1966. 4) A discontinuity in the longitude of the Red Spot is present between 26 and 28 March 1966. Before this date, the longitude of the Spot averaged about 26°.7; afterwards the mean longitude was about 28°.3.

Additionally, the Red Spot may make small, erratic shifts, usually of not more than 0°.5 in longitude, lasting for about one day. Such small variations in longitude would be difficult to confirm, since even ideally the Red Spot can be accurately measured only about 30% of the time.

Thus the motion of the Red Spot in longitude is extremely complicated, with at least six components, four of them erratic, having the following approximate periods: fifty years, eight years, two years, three months, one week, and one day (suspected).

DIMENSIONS OF THE RED SPOT

After remaining nearly constant at 23°.0 during the first half of the apparition, the length of the Red Spot decreased to about 20°.5 near the end of the apparition. The mean length of the Red Spot during 1965-66 was 22°.5. The mean width of the Red Spot was 10°.9. Thus the dimensions of the Spot continued to decrease, as they have since 1962.

SEB-STB SPOTS IN 1965-66

During the middle of the apparition, several rapidly moving spots were observed on the south edge of the south component of the South Equatorial Belt and on the north edge of the South Temperate Belt. Five STB spots were observed to move in the direction of decreasing longitude, with a mean rotation period of $9^h52^m59^s$. Fifteen SEB spots, moving in the opposite direction, had a mean period of $9^h58^m05^s$. Of these markings, one STB feature, designated "A," and two SEBs features, "B" and "C," were very prominent; indeed, they retained their identities as they traversed the outer boundary of the Red Spot. The STB spot "A" made a complete counterclockwise circuit around the Red Spot in about nine days. The SEB spots swept along the north edge of the Red Spot and continued along the SEBs for about 20° following the Red Spot, where their progress was halted.

From accurate measures of photographic plates, it was determined that Spot A had a rotation period of $9^h53^m21^s.4$, Spot B had a period of $9^h57^m51^s.1$, and Spot C had a period of $9^h58^m18^s.2$.

INTERACTIONS BETWEEN THE RED SPOT AND OTHER JOVIAN FEATURES

In Figure 1, the Red Spot is seen to exhibit a sinusoidal drift in longitude, with a period of approximately eighty-eight days. The amplitude of the oscillation varied, but the period never differed by more than ten days from the mean value. An inspection of the longitudes reported in (I) shows that this oscillation has persisted since the measuring program began in 1962 (Figure 3). The smaller number of photographs obtained in earlier years, however, prevented this oscillation from being previously recognized.

A hypothetical feature moving in the direction of increasing longitude, travelling 360° in eighty-eight days with respect to the Red Spot, assuming a mean Red Spot drift in System II longitude of +0°.0143 per day, will have a rotation period of $9^h58^m30^s.0$. A feature also moving 360° in eighty-eight days with respect to the Red Spot, but in the opposite direction, will have a rotation period of $9^h52^m53^s.9$. A change of 19.4 seconds in the rotation periods of the hypothetical spots will change by ten days the time between successive conjunctions with the Red Spot.

Jovian features with such rotation periods are rare; during the seventeen apparitions between 1945 and 1964, only nine instances of mid-latitude spots having very short rotation periods were observed (Reese, 1965)--five times in the NEB and four times on the S/SEBn. Spots having very long rotation periods were observed during three apparitions, each time on the SEBs during an SEB disturbance. In fact, the only markings in the southern hemisphere of Jupiter with rotation periods near 9^h53^m and 9^h58^m have been associated with either an SEB disturbance or the Circulating Current, discussed at length in The Planet Jupiter (Peek, 1958, pp. 155-180). Briefly, during an SEB disturbance a small dark spot forms between the SEBs and the SEBn. Numerous other features, which move along the SEBs in the direction of increasing longitude and along the SEBn in the direction of decreasing longitude, erupt in the same longitude as the dark spot. The Circulating Current contains markings which also move along the SEBs in the direction of increasing longitude, but also has associated with it markings which move along the north edge of the STB in the opposite direction. Before 1939, when the South Tropical Disturbance was visible, the SEBs spots were apparently reflected by the preceding end of the Disturbance, and returned

along the STB. However, during the apparition of 1962-63, a Circulating Current was observed without the South Tropical Disturbance being visible (Reese, 1963). Thus the spots described in the preceding section of this paper are similar in many respects to the features observed in the Circulating Current or during an SEB disturbance, although it is not known if a relationship exists.

As is shown in Figure 1, and as mentioned previously in this paper, the Red Spot rapidly increased in longitude as Spot A approached its following end. As Spots B and C passed north of the Red Spot, the scatter of the longitude measurements doubled, implying erratic shifts of the Red Spot in longitude or variability in the visibility of the ends of the Spot. In addition, the Red Spot became less distinct at this time. In Figure 4, a sharp increase in smoothed length of about 0°.5 is noted as Spot A neared the Red Spot. As Spot B approached, the length decreased at a more rapid rate. This decrease may be less significant in this case, since the general trend for the preceding months had been for the length to decrease.

As illustrated in Figure 5, a very prominent increase in latitude, amounting to more than 0°.75, took place at the time Spot A was traversing the outer boundary of the Red Spot. This is the first time since the measuring program was initiated that another Jovian feature could be suspected to have interacted with the Red Spot. It is significant that both the north and south edges of the Red Spot moved southward simultaneously; this implies that an interrelation exists between the north and south edges of the Spot. After this southward movement occurred, the width began to decrease, a trend which continued throughout the remainder of the apparition (Figure 6).

The rapidly moving SEB-STB spots moved ± 360° with respect to the Red Spot in 91 days, which is very close to the 88-day period of the oscillation in the Red Spot's longitude. Since the spots apparently influenced the behavior of the Red Spot, it seems reasonable to ask if there is a relationship between these rapidly moving features and the longitudinal motion of the Red Spot.

In presenting his Taylor Column hypothesis of the origin of the Red Spot, Hide (1963) has proposed that the presence of the Red Spot Hollow indicates a more laminar flow around the north edge of the Spot. Evidence for the support of this supposition has been presented in (I). If, indeed, the flow is more laminar around the north edge of the Red Spot, then features on the STB should be expected to influence to Red Spot more than features on the SEB. As was discussed earlier, this was quite possibly the case during the 1965-66 apparition; Spot A may well have produced a temporary increase in the length and longitude of the Red Spot and an increase in its latitude, while Spots B and C apparently had a more subtle short-term influence on the Red Spot, although they may have caused a long term decrease in Red Spot length beginning in December 1965.

STB spots are seen only infrequently, while the Red Spot has oscillated in longitude for a least the past four apparitions. If the Red Spot is a Taylor Column, a disturbance of the invisible lower levels of the column would presumably influence the behavior of the upper part, which can be observed. Thus the "source" of the STB spots, or perhaps some other active region in the same latitude which is not necessarily related to the STB spots, situated in the lower levels of the atmosphere, could produce the observed oscillation in Red Spot longitude, even though no STB spots are observed.

It must be stated that the ideas presented above are, by necessity, preliminary. The Red Spot has been accurately measured only since 1961, and it is too early to be certain of relationships between the Red Spot and other Jovian features. The evidence presented above for a relationship between STB spots and the Red Spot cannot be taken as conclusive -- in fact, it has been suggested that SEBs spots, rather than STB spots have the greater influence on the behavior of the Red Spot. In short, accurate measurements of the Red Spot must be continued for at least several more apparitions before it will be possible to postulate relationships between the Red Spot and other features with any certainty.

ACKNOWLEDGMENTS

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TABLE I

RED SPOT ROTATION RATES, 1965-66

	Limiting Dates	Rotation Period	P.E.	Drift °/day	P.E.	Limiting Longitudes
1965	1 Jul-15 Aug	$9^h55^m41^s.48$	$\pm 0^s.28$	0°.0206	±0°.0069	24.3--25.2
	15 Aug- 5 Sep	37.78	.37	-.0692	.0091	25.2--23.8
	5 Sep-25 Oct	41.92	.26	.0316	.0064	23.8--25.5
	25 Oct-30 Nov	40.01	.18	-.0156	.0043	25.5--25.0
	30 Nov-27 Jan	42.56	.19	.0470	.0045	25.0--27.5
1966	27 Jan-10 Feb	38.35	.40	-.0552	.0096	27.5--26.6
	10 Feb-26 Mar	40.87	.28	.0054	.0067	26.6--26.8
	(26 Mar-28 Mar)	$(56^m17^s.91)$	---	(.9069)	---	(26.8--28.5)
	28 Mar- 4 Jun	40.40	.18	-.0058	.0044	28.5--28.1
Mean during the apparition	1 Jul 65- 4 Jun 66	41.09	.05	.0112	.0013	24.3--28.1
Mean between successive oppositions	13 Nov 64- 18 Dec 65	41.11		.0118		21.0--25.7

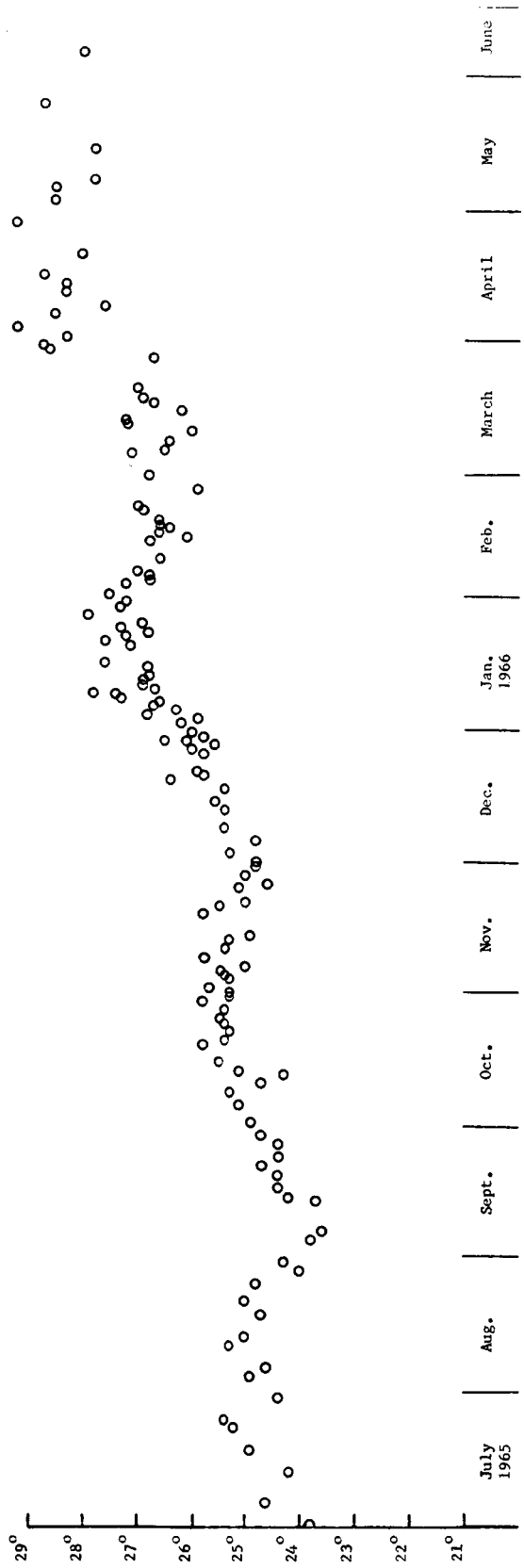

Figure 1
System II Longitude of Red Spot, 1965-66

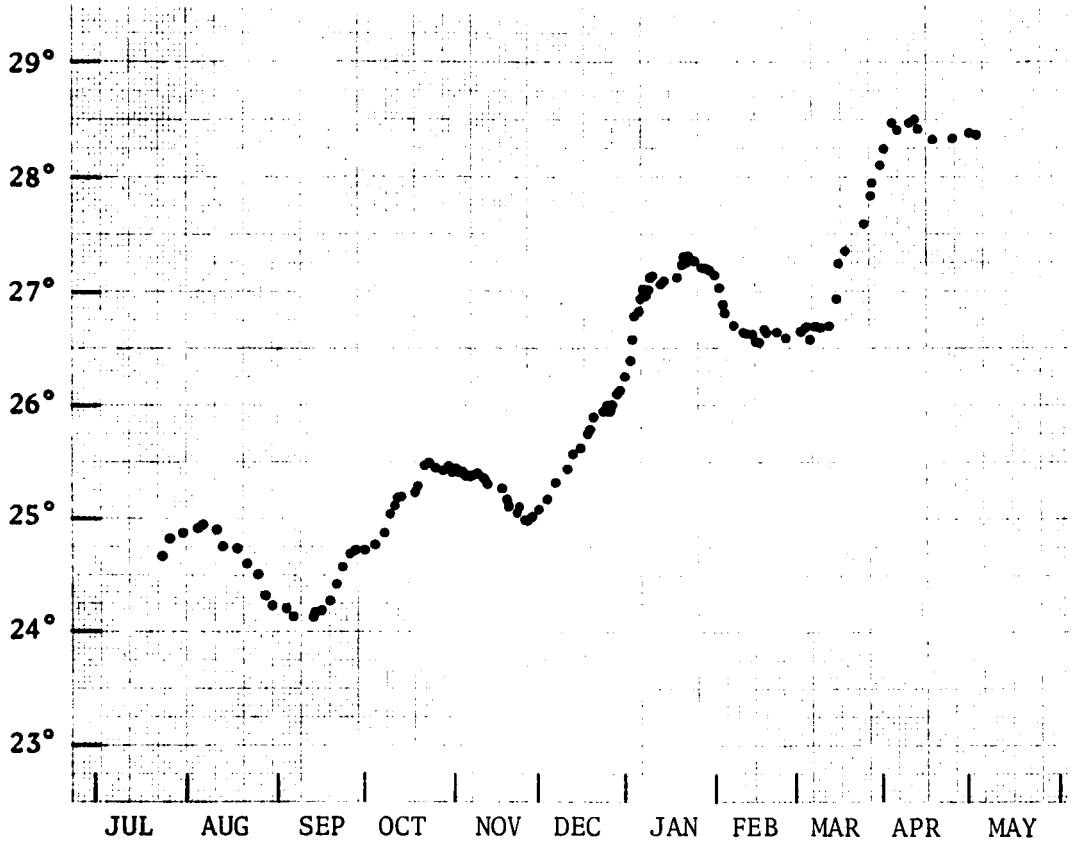

Figure 2 Longitude II of Red Spot, 1965-66 9-Plate means

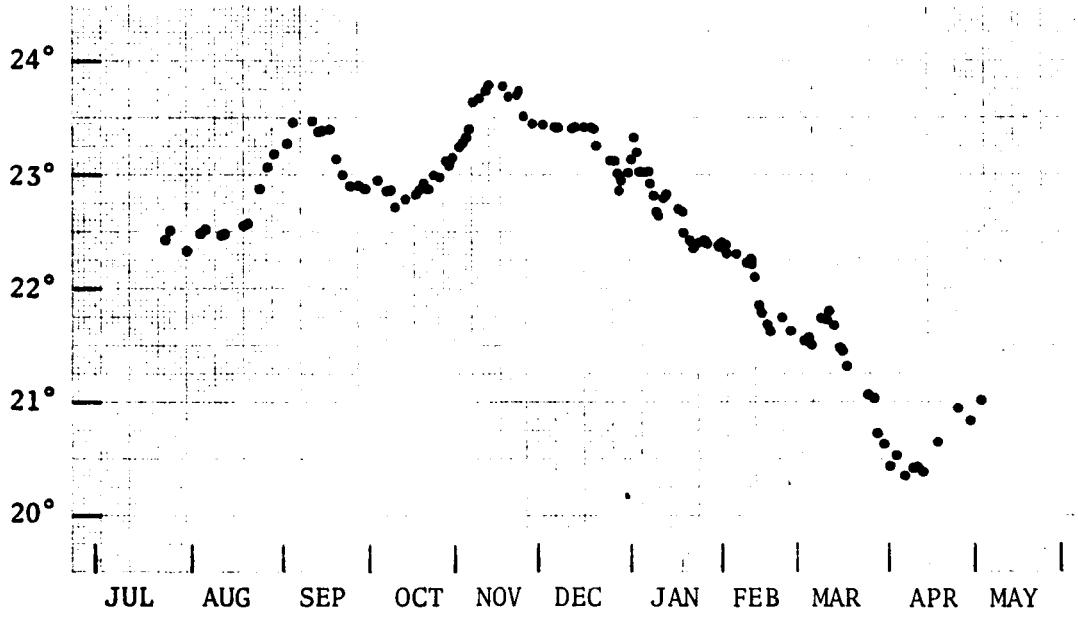

Figure 4 Length of Red Spot, 1965-66 9-Plate means

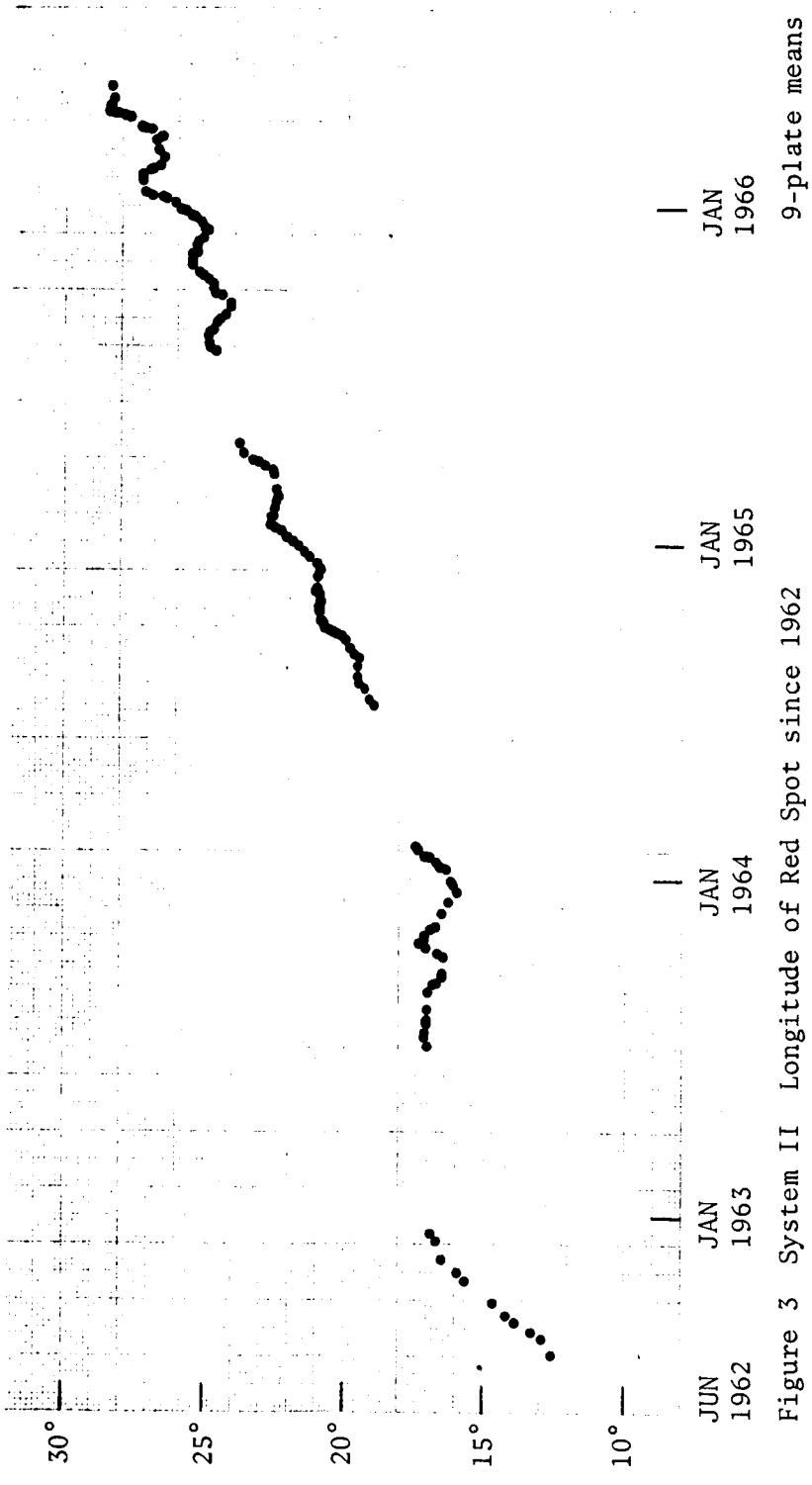

Figure 3 System II Longitude of Red Spot since 1962

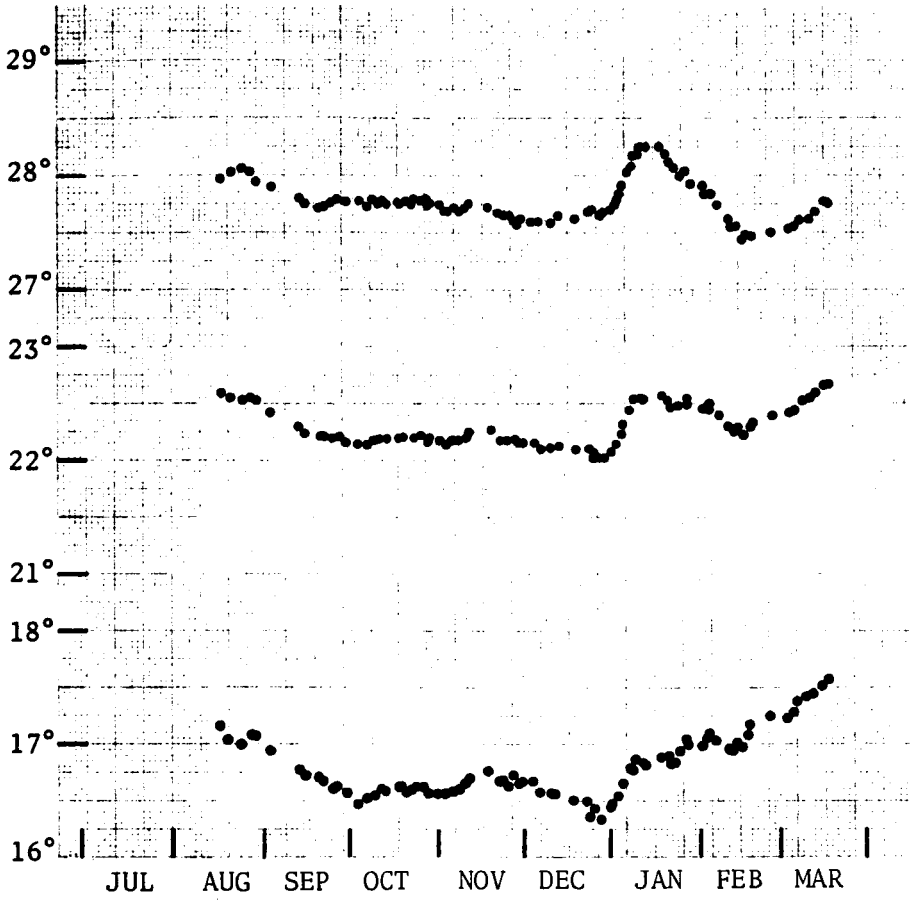

Figure 5 Latitude of Red Spot, 1965-66 9-plate means

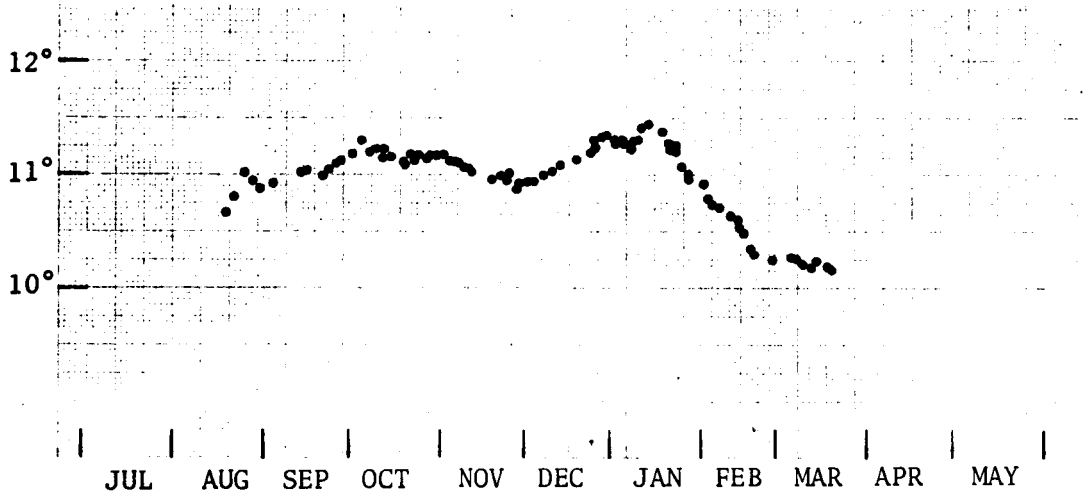

Figure 6 Width of Red Spot, 1965-66 9-plate means